Measurement of Time Varying Volume Scatter

Jules S. Jaffe
Scripps Institution of Oceanography
University of California, San Diego
La Jolla, CA 92093-0238
phone: (858) 534-6101 fax: (858) 534-7641 email: jules@mpl.ucsd.edu

Award Number: N00014-05-1-0115
http://jaffeweb.ucsd.edu/

LONG-TERM GOALS

The major long-term scientific goal of this program is to understand the small-scale optical properties of the ocean. This includes the spatial and temporal inhomogeneities that occur naturally over scales from km to mm. The importance of this area of inquiry is underscored by both environmental and practical concerns. In an environmental context, the radiative transfer of light in the ocean is dependent on not only the average but also the small scale (cm – m) optical properties. The role that these inhomogeneities play in light transmission is unexplored to due a lack of in-situ data. In a practical sense, improved characterization of the environment is critical in understanding and predicting the outcome of Navy systems that are in and also planned for use.

OBJECTIVES

The main objective of this project is to create and deploy a "next generation" scientific instrument that can measure spatial and temporal inhomogeneities in the volume scattering function $\beta(\theta,\vec{r},t)$. Measurement of this function provides both empirical and environmental information about the state of the ocean. In addition, the interpretations of those patterns (scales of spatial inhomgeneities, temporal decorrelation time) can be used to interpret both the constituents and also the dynamics of sea water: What are the temporal and spatially varying scattering patterns which are observed? Our most near term goals is to create an economical device that is capable of measuring these functions and to use this device to measure them in the lab and at sea.

APPROACH

Task 1: Development of a prototype to record volume scattering function.

The first task to be performed under this project is the fabrication of a prototype VSF using existing CCD camera technology. We are especially interested in pushing the limits of the CCD technology because it presents many advantages for sensor development. This includes the fabrication of very high-resolution angular sensors (for inferring particulate concentration and nature) and also the simplicity (and presumably cost effectiveness) of devices based on this technology. The various trade-offs in CCD technology include increased read out rate with increased sensor noise versus slower read out rate with decreased sensor noise. Various geometric configurations of sensors, sensor screens upon which the scattered patterns will be projected, sample volume, and receiver geometry will be tested.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2007**	2. REPORT TYPE **Annual**	3. DATES COVERED **00-00-2007 to 00-00-2007**

4. TITLE AND SUBTITLE **Measurement Of Time Varying Volume Scatter**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of California, San Diego,Scripps Institution of Oceanography,La Jolla,CA,92093**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S)
	11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
code 1 only

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**5**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Task 2: Characterization of volume scatter from both calibrated and collected suspensions:

An important aspect of our work is the calibration and characterization of our system for collecting VSF(t) information. As described previously, for initial studies, particles with small hydrodynamic radii will be used to judge the performance of the CCD based scattering meter.

Task 3: Collect data from in-situ suspensions:

At the end of year 2, in FY 06, we used the FIDO vehicle in order to deploy and observe high-resolution temporal and spatial scatter patterns from undisturbed and freely suspended oceanic particles. Simultaneous measurements of the volume scatter and also ancillary measurements such as conductivity, temperature, and salinity will permit new insights into the distribution of scatterer in the water column and their relationship to oceanography.

Task 4: Development of signal and image processing techniques:

A significant aspect of this program will be the development of signal and image processing techniques. Since the ultimate end result of the work, will be characterization of both spatial and temporal decorrelation times, our algorithms will be geared toward the development of techniques that will computation of these functions. The goals of the image and signal reconstruction efforts will be aimed towards: (1) Using the calibrated data (as discussed above) in order to obtain "correct" estimates of the Volume Scattering Functions. (2) Taking the data from these VSF and computing coherence times (for the lab experiments). (3) Developing image processing algorithms in order to treat the VSF data as "images" in contrast to simple time varying sequences. (4) Analyzing these coherence data, looking at the inversion of aggregated and particulate matter in order to compute the magnitude of the refractive index fluctuations and thus infer something about the structures that are scattering the light.

RESULTS

Tasks 1 and 2: Fabrication and testing of a new type of VSF based on CCD technology: During the past year we have continued to work on the design and development of a new type of scattering meter that uses CCD technology for imaging the scattered field instead of an array of PMT receivers or APDs. The instrument was built last year with ONR funding and several examples of nearly omni-directional scatter were shown in our previous annual report. In this document, we report the development of an algorithm for particle sizing to sub wavelength accuracy under the Task 4 category below. Continued tests of the new scattering meter will resume this year in lieu of these new results related to the theoretical interpretation of the data.

Task 3: In situ measurement of the Volume Scattering Function on the FIDO vehicle: In the fall of 2006 we completed our 7 day cruise in order to measure the in-situ scattering of light and temporal correlation from successive light patterns. The cruise was conducted between Aug 31st – Sept 7th on the R/V WECOMA (Oregon State University). The cruise protocol consisted of using 4 of the nights for characterization of particles and particle size distributions and 3 of the nights for measurement of small-angle volume scattering functions (the system can only work at night because ambient light dominates the light scattered from volume suspensions). The cruise was extremely successful in that data was collected on each evening. Over the course of the 7 days, we performed a set of approximately 30 profiles. The FIDO vehicle was equipped with two CTDs, fluorometer, SCAMP temperature micro profiler and an ADCP current meter. Data collected during this cruise was shown

in last years report. We have continued to work on processing this data set and are developing new algorithms (as in Task 4 below) to infer small-scale scatter from the data.

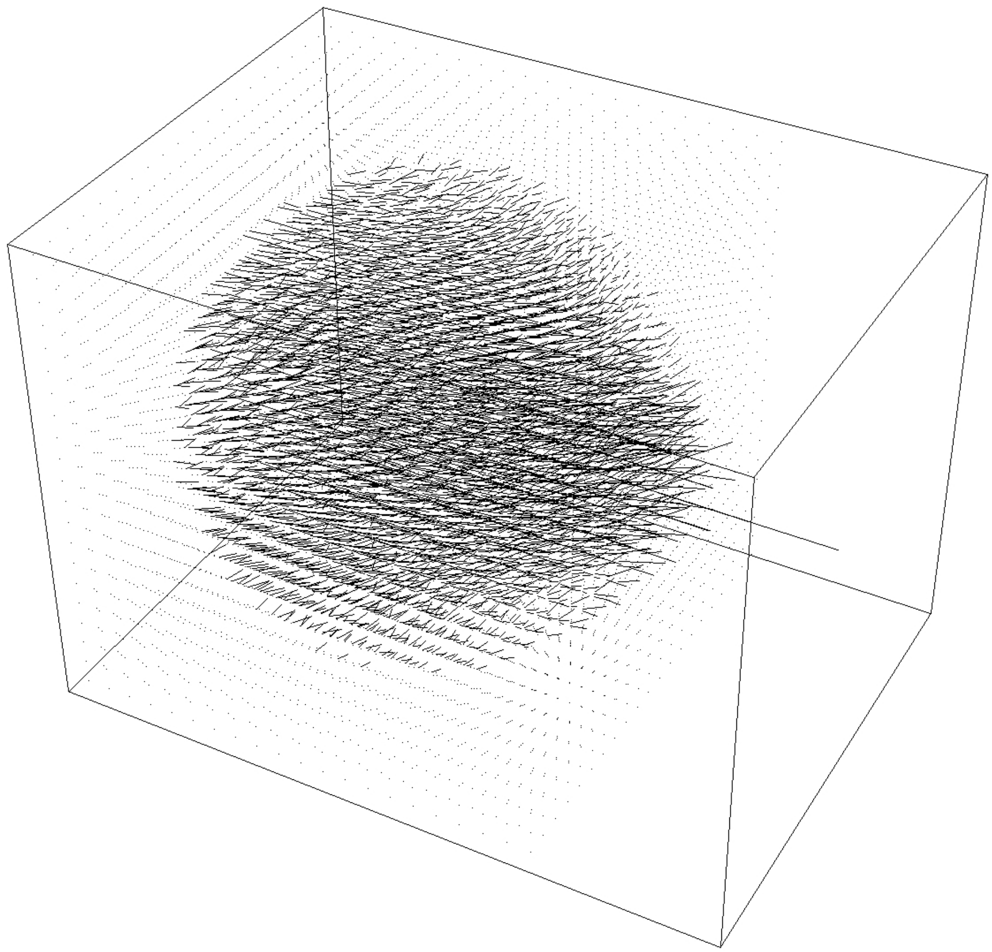

Figure 1: A depiction of the internal electromagnetic field of a 1 μm particle embedded in sea water. The particle was simulated on a grid of dimensions (21)^3 using the Mie theory expressions for the internal field. A linear phase gradient was found to exist in the field, which facilitated the use of a tomographic theory for particle size inversion.

Task 4: The development of signal and imaging processing algorithms. This task has consumed the major part of our efforts for this FY. Briefly, a continuing challenge in ocean optics has been to characterize the particle size distributions in the ocean. At the larger end of the scale (10 – 100 μm) in-situ imaging techniques can be used because the wavelength of light is much larger than the particle diameter. Although this method presents challenges from a deployment and automated processing point of view, the imaging related aspect of this task are straightforward. On the other hand, imaging particles at nearly or smaller than the wavelength of light (.1 – 2 μm) has proven to be a challenge from a very basic point of view. Based on our suspicions that the largest angle scattering component of the light contains information about the smallest spatial scales inside of an object a set of Mathematica programs were written in order to examine whether traditional algorithms for tomgoraphic processing could be used in order to infer size. Figure 1 contains a visualization of the internal field. Briefly, the results indicate that there is a simple relationship between the internal electromagnetic field and the scattered radiation. This then permits the identification of the complex

amplitude of the scattered field as values of the Fourier coefficients of the internal structure at a specific set of sinusoid waves via the far-field Fourier diffraction theory. Next, taking advantage of this relationship, a simple algorithm was used to invert for both particle size index and refractive index via inverse tomographic theory. The method was found to work well a set of conditions that are extremely relevant to the ocean: low contrast particles that are small. Results were published in Optics Express (September, 2007).

RELATED PROJECTS

Several on-going projects in Jaffe's lab are related to this project. As stated above, the FIDO vehicle, funded by NSF with subsequent funding by ONR will be used to measure the VSF and its fluctuations. This vehicle, under development for almost a decade now has provided a reliable and non invasive way to sample the upper 50 m of the ocean via, most recently, a three dimensional Particle Imaging Velocimetry system that was constructed under NSF funding. The extension of studies to examine the VSF is a natural area of exploration that can take place quite economically due to these companion projects. In addition, Jaffe has been funded by a private foundation (The Seaver Foundation) to characterize the use of diffraction tomography in order to infer the dynamics of small (cm size) volumes. The goals of that project are complementary (however not identical) to those of this one.